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Fatigue and Weatherability Studies of Aramid-Fiber Rope Slings

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FATIGUE AND WEATHERABILITY STUDIES OF ARAMID-FIBER ROPE SLINGS

Nixon Halsey and Leonard Mordfin

ABSTRACT

Tests were carried out on twenty-six sling-leg specimens, fabricated from aramid-fiber ropes, as part of a program to develop improved external cargo slings for helicopters. The ropes included both parallel-strand and cabled-strand varieties, in three different tensile capacities. The tests were intended to evaluate the reductions in rope strength caused by fatigue loading and by exposure to simulated weathering. It was found that the fatigue capabilities of some of the ropes may not be entirely satisfactory; but, because of inadequacies in the end fittings installed by the rope manufacturers, thorough evaluations were not possible. The results indicate that the performances of the ropes could be enhanced through the use of more efficient end fittings, and suggestions for the development of such end fittings are offered.

Key Words: Aramid-fiber rope; breaking load, rope; cable, aramid-fiber; end fittings, rope; fatigue damage; rope, aramid-fiber; slings, cargo; terminations, rope; weathering, simulated.

1. INTRODUCTION

This report presents the results of one phase of a program to advance the technology of external cargo slings for helicopters. The objective of the program is to develop a family of cargo sling assemblies which offer improved handling characteristics and significant weight reductions. The work described here was intended to explore the potential improvements which could be achieved through the use of a newly developed, synthetic fiber material for the slings. To this end, tensile, fatigue and simulated weathering tests were carried out on prototype sling legs, in three tensile capacities, fabricated from two varieties of aramid-fiber rope.

This investigation was carried out in the Engineering Mechanics Section of the National Bureau of Standards (NBS) under the sponsorship and with the financial assistance of the U. S. Army Air Mobility Research and Development Laboratory (AAMRDL).

The test conditions for the tensile and fatigue tests were specified by AAMRDL. The simulated weathering tests were designed by NBS.

2. SPECIMENS

The prototype sling-leg specimens, consisting of aramid-fiber ropes with end fittings attached, were provided to NBS by the sponsor in two different rope configurations and in three tensile capacities, making six rope styles in all. Variations in rope jacketing materials and in end fittings raised the total number of specimen styles to nine. One of the two rope configurations consisted of rope strands gathered together in parallel, while in the other the rope strands were cabled together. The tensile capacities and related information are given in Table 1.

2.1 Fiber and Yarn Characteristics

The ropes were manufactured from aramid-fiber yarns consisting of 1.5-denier filaments. Typical yarn properties are given in Table 2. The singles yarns used for all but one of the rope styles were comprised of approximately 1000 untwisted filaments and had a linear density of 1500 denier. The high-capacity parallel-strand ropes utilized 15 000-denier singles yarns containing approximately 10 000 filaments. These denier values have the following equivalents in other engineering units:

denier	lb per 1000 ft	mg/m
1.5	0.00011	0.17
1500.	0.11	170.
15 000.	1.1	1700.

2.2 Parallel-Strand Rope Construction

Constructional yarns for the parallel-strand ropes were formed by plying several singles yarns together. Each rope strand was assembled from ten constructional yarns twisted together in a direction opposite to that of the individual constructional yarns. The several rope strands were gathered together without twist and enclosed in a jacket. In order to achieve a relatively torque-free product, each rope incorporated some strands with right lay and some with left lay. The low-capacity rope, for example, had two strands twisted right and two twisted left. The medium size had nine strands in all and the high-capacity rope, fourteen strands.

2.3 Cabled-Strand Rope Construction

Constructional yarns for the cabled-strand ropes were formed from groups of singles yarns gathered together and impregnated with polyurethane.

The low-capacity rope was comprised of nineteen rope strands, each containing seven constructional yarns twisted together with left lay. The twelve outer rope strands were wound with right lay around six strands which were wound with left lay around one center strand.

Table 1 - Property Requirements of Sling Legs

Capacity designation	Rated breaking load		Rated working load		Required fatigue life[a]	
					No. of cycles	Frequency
	lbf	(kN)	lbf	(kN)		Hz
low	17 500	(78)	10 000	(44)	5 082 000	2.57
medium	36 000	(160)	25 000	(111)	4 326 300	2.19
high	56 000	(249)	40 000	(178)	3 330 000	1.68

[a] Spectrum loading conditions.

Table 2 - Typical Properties of Aramid-Fiber Yarn[a]

Specific gravity	1.44	
Filament diameter	0.00047 in	(12 μm)
Filament denier	1.5	
Break elongation[b]	3 to 4 percent	
Tensile strength[b]	400 000 lbf/in^2	(2.8 GPa)
Young's modulus[b]	9×10^6 lbf/in^2	(62 GPa)

[a] According to yarn manufacturer.

[b] Based on dry yarn test.

The medium-capacity rope consisted of six rope strands wound with left lay around an independent rope core. Each of these strands was composed of nineteen constructional yarns twisted together with right lay. The rope core consisted of nineteen strands, each containing seven constructional yarns. The twelve outer strands of the rope core were wound with left lay on six strands which were wound with right lay on the center strand.

The high-capacity cabled-strand rope also consisted of six rope strands wound with left lay around an independent rope core. Each of these strands was comprised of 37 constructional yarns (18 right, on 12 left, on 6 left, on 1). The rope core consisted of seven strands, six wound right on one. Each of these strands was comprised of seven constructional yarns twisted together with left lay.

2.4 Jackets

The parallel-strand ropes were all jacketed with black braided nylon that had been treated with neoprene to reduce moisture penetration (Figure 1).

The low-capacity cabled-strand ropes had extruded polyurethane jackets (Figure 2a). One out of three medium-capacity cabled-strand ropes also had an extruded polyurethane jacket (Figure 2b); the other two had thicker, polypropylene jackets (Figure 3). The high-capacity cabled-strand ropes all had white braided polyester jackets (Figure 4).

2.5 End Fittings

All of the specimens were furnished with potted, compression-type (conical-basket) end fittings that had been installed by the rope manufacturers.

The parallel-strand ropes used commercial, forged-steel, open spelter sockets of the type that is conventionally used for steel wire rope (Figure 1). The tops of the baskets had been built up with tape to provide a longer potting length. Where the ropes entered the sockets, the jackets were reinforced with tape.

The low-capacity cabled-strand ropes were fitted with commercial potting heads of a type that is widely used for synthetic-fiber rope (Figure 2a). In the medium size, two cabled-strand ropes were furnished with similar, but larger, potting heads that had been reinforced with conical metal sleeves (Figure 2b); and one cabled-strand rope was fitted with open spelter sockets similar to those used on the parallel-strand ropes. Experimental end fittings were used on the high-capacity cabled-strand ropes. Two of these ropes were furnished with steel fittings of the type shown in Figure 4, bottom, and one had proprietary phosphor-bronze fittings such as that illustrated in Figure 5.

The descriptions of the specimens are summarized in Table 3. The table also gives the diameters of the ropes, and the numerical designations of the specimens of each style which were subsequently tested.

3. PRELIMINARY TENSILE TESTS

Specimens of four different rope styles were subjected to tensile tests in order to obtain some preliminary indications regarding the response of the specimens to tensile load. These tests were performed in universal testing machines at a crosshead speed of 0.75 in/min (0.32 mm/s). Each specimen was subjected to five or ten cycles of load, from zero to a predetermined load level and back to zero, before the load was increased to failure. Each specimen failed near one of its end fittings (see, for example, Figure 6) where the resin, which had been used to pot the fittings, had seeped into the rope fibers outside of the fittings before it was cured. It is not obvious whether this seepage was due to normal flow under the influence of gravity, or to a wicking action of the aramid fibers, or both. In any event, the subsequent curing of the resin destroyed the normal flexibility of the ropes near their end fittings.

The breaking loads attained by the specimens are given in Table 4, together with the rated breaking loads. It may be seen that the specimens failed, more often than not, to attain their rated loads. In the worst case, Specimen No. 1, the actual breaking load was only 88 percent of the rated value. Interestingly, however, the only specimen which actually exceeded its rated value (No. 2), was nominally identical to this one.

The table also lists the free lengths of the specimens, measured both before and after the pre-cycling of load. (Free length is defined as the length of a specimen between end fittings.) Differences between the original free lengths of specimens of different styles reflect differences in the lengths of their end fittings, since all of the specimens were manufactured to have the same approximate length between the clevis pins on their end fittings.

4. FATIGUE STUDIES

Specimens of several styles were subjected to axial tension fatigue tests using spectrum loading. Two different kinds of block spectrums were specified. The first consisted of three blocks of cycles, applied in order of increasing load levels. The second consisted of two blocks which were applied alternately. All of the tests were carried out on a 24 hours-per-day basis, in a 50 000-lbf (222-kN) capacity, electrohydraulic fatigue testing machine [1].

Table 3 - Specimen Descriptions

Rope configuration[a]	Tensile capacity[b]	Singles yarn size	Rope construction[c]	Diameter[d]		Jacket	End fittings	Specimen Nos.
		denier		in	(mm)			
parallel	low	1500	4 x 10	7/16	(11)	nylon braid[e]	spelter sockets	1,2,12,14,18,19
parallel	medium	1500	9 x 10	11/16	(17)	nylon braid[e]	spelter sockets	5,6,7,11,15,21
parallel	high	15 000	14 x 10	7/8	(22)	nylon braid[e]	spelter cockets	9,10,22
cabled	low	1500	19 x 7	1/2	(13)	polyurethane	potting heads	3,4,8,13,20
cabled	medium	1500	6 x 19 IRC[f]	11/16	(17)	polyurethane	potting heads	23
cabled	medium	1500	6 x 19 IRC[f]	11/16	(17)	polypropylene	potting heads	16
cabled	medium	1500	6 x 19 IRC[f]	11/16	(17)	polypropylene	spelter sockets	17
cabled	high	1500	6 x 37 IRC[g]	15/16	(24)	polyester braid	exptl. steel	24,26
cabled	high	1500	6 x 37 IRC[g]	15/16	(24)	polyester braid	exptl. bronze	25

(a) Refers to parallel-strand or cabled-strand configurations.
(b) Numerical ratings are given in Table 1.
(c) (Number of rope strands) x (number of constructional yarns per rope strand).
(d) Approximate outer diameter including jacket.
(e) Neoprene-impregnated.
(f) Independent rope core, 19 x 7.
(g) Independent rope core, 7 x 7.

Table 4 - Preliminary Tensile Tests

Rope configuration	Specimen No.	Rated breaking load	Testing machine	Free length before cycling	Cycling load	No. of cycles	Free length after cycling	Measured breaking load
		lbf (kN)		in (mm)	lbf (kN)		in (mm)	lbf (kN)
parallel	1	17 500 (78)	a	42.4 (1077)	2500 (11.1)	5	42.5 (1080)	15 350 (68.3)
parallel	2	17 500 (78)	a	42.5 (1080)	7500 (33.4)	5	42.6 (1082)	18 650 (83.0)
parallel	5	36 000 (160)	a	38.1 (968)	7500 (33.4)	5	38.2 (970)	36 000 (160.0)
parallel	9	56 000 (249)	b	33.1 (841)	28 000 (124.6)	10	33.6 (853)	51 150 (227.5)
parallel	10	56 000 (249)	b	33.9 (861)	28 000 (124.6)	10	34.4 (874)	50 600 (225.1)
cabled	3	17 500 (78)	a	26.0 (660)	2500 (11.1)	5	26.0 (660)	17 300 (77.0)
cabled	4	17 500 (78)	a	26.6 (676)	7500 (33.4)	5	26.6 (676)	17 300 (77.0)

a. 400,000-lbf (1.78-MN) capacity, vertical, screw-powered testing machine [1]*.
b. 100,000-lbf (0.44-MN) capacity, horizontal, hydraulically powered testing machine [1].
* Numerals in square brackets refer to similarly numbered references cited in Section 9.

4.1 Increasing-Load-Spectrum Tests

Three increasing-load spectrums were used, as given in Table 5. Within each block of each spectrum, the minimum load level is 60 percent of the maximum load level. Spectrums B and C, intended for the medium-capacity specimens, have identical load levels and differ only in the numbers of cycles; Spectrum C has approximately one-fourth the number of cycles as Spectrum B. Spectrum A was intended for the low-capacity specimens. Expressed as percentages of the respective rated working loads, the load levels in Spectrum A are identical to those in Spectrums B and C.

Five specimens were tested using these spectrums. The results are given in Table 6. Malfunctions of the automatic spectrum-programming equipment for the fatigue machine led to several deviations, in numbers of cycles, from the specified spectrums; these are cited in the footnotes to the table. The results show that only one specimen, a low-capacity parallel-strand rope, survived the fatigue tests without failure. A low-capacity cabled-strand specimen and three medium-capacity parallel-strand specimens all failed before completing the specified test spectrums. In each of these cases, however, the failure was due to an end fitting and not to a deficiency in the rope itself.

4.2 Alternating-Block-Spectrum Tests

These tests consisted of basic constant-load-amplitude fatigue tests which were interrupted at periodic intervals with the application of five cycles to a higher load level ("spikes"). The interruptions were applied after each 50 000-cycle interval whenever such interval occurred during regular working hours (8:30 am - 5:00 pm, Mon-Fri). Table 7 lists the basic and the spike load levels for each rated capacity of the specimens. The maximum load levels of the basic blocks represent the same approximate percentage of the respective rated working loads. In the spectrums for the low- and medium-capacity specimens, the minimum loads are the same for the basic blocks and the spike blocks; for the high-capacity specimens, the minimum load of the spike block equals the maximum load of the basic block.

The results of alternating-block-spectrum fatigue tests on seven specimens are given Table 8. Two of the specimens were of the parallel-strand variety. One of these, a low-capacity rope, pulled out of one of its end fittings prematurely. The other, an intermediate-capacity specimen, survived the entire fatigue test without failure.

Of the five cabled-strand specimens which were tested, three, representing one of each tensile capacity, survived without failure. A fourth, of medium-capacity, suffered a partial failure (Figure 3), but nevertheless survived the entire test. The fifth, a high-capacity specimen, failed in its free length relatively early in the test (Figure 4a).

Table 5 - Increasing-Load Fatigue Spectrums

	Spectrum A	Spectrum B	Spectrum C
First Block			
Maximum load, lbf (kN)	2500 (11.1)	6250 (27.8)	6250 (27.8)
Minimum load, lbf (kN)	1500 (6.7)	3750 (16.7)	3750 (16.7)
No. of cycles	508 200	432 630	108 158
Second block			
Maximum load, lbf (kN)	5000 (22.2)	12 500 (55.6)	12 500 (55.6)
Minimum load, lbf (kN)	3000 (13.3)	7500 (33.4)	7500 (33.4)
No. of cycles	508 200	432 630	108 158
Third block			
Maximum load, lbf (kN)	10 000 (44.5)	25 000 (111.2)	25 000 (111.2)
Minimum load, lbf (kN)	6000 (26.7)	15 000 (66.7)	15 000 (66.7)
No. of cycles	3 811 500	3 244 725	811 181
Total No. of cycles	4 827 900	4 109 985	1 027 497

Table 6 - Increasing-Load-Spectrum Fatigue Tests

Rope configuration	Specimen No.	Tensile capacity	Free length in	Free length (mm)	Spectrum	Test frequency Hz	Total cycles applied	Remarks
parallel	12	low	43.2	(1097)	A	10.0	4 598 446[a]	b
parallel	7	medium	38.6	(980)	B	10.0	1 241 790	c
parallel	6	medium	d	(d)	B	2.19	1 372 016[e]	c
parallel	11	medium	37.3	(947)	C	10.0	286 830	c
cabled	8	low	26.0	(660)	A	2.57	2 087 027	f

a. Includes 586 541 cycles in second block, and 3 503 705 cycles in third block.
b. Test terminated without failure.
c. Failed adjacent to end fitting where potting compound had seeped into the free length (cf Fig. 6).
d. Not measured.
e. Includes 624 001 cycles in first block.
f. Fracture of lip on potting head of one end fitting (Fig. 7).

Table 7 - Alternating-Block Fatigue Spectrums

	Tensile capacity of specimen		
	low	medium	high
Basic block			
Maximum load, lbf (kN)	6800 (30.2)	17 000 (75.6)	27 270 (121.3)
Minimum load, lbf (kN)	6200 (27.6)	15 900 (70.7)	24 930 (110.9)
Frequency, Hz	5	5	4
No. of cycles per block	50 000	50 000	50 000
Spike block			
Maximum load, lbf (kN)	10 270 (45.7)	21 000 (93.4)	33 600 (149.5)
Minimum load, lbf (kN)	6200 (27.6)	15 900 (70.7)	27 270 (121.3)
Frequency, Hz	2	2	2
No. of cycles per block	5	5	5
Total No. of cycles	3 456 000	2 950 000	2 264 000

Table 8 - Alternating-Block-Spectrum Fatigue Tests

Rope config.	Specimen No.	Tensile capacity	Free length		No. of cycles applied			Remarks
					basic	spike	total	
			in	(mm)				
parallel	14	low	42.8	(1087)	937 912	35	937 947	a
parallel	15	medium	39.4	(1001)	2 949 920	80	2 950 000	b
cabled	13	low	25.9	(658)	3 455 925	75	3 456 000	b
cabled	16	medium	25.8	(655)	2 949 940	60	2 950 000	b
cabled	17	medium	44.0	(1118)	2 951 778	50	2 951 828	c
cabled	25	high	29.6	(752)	283 173	15	283 188	d
cabled	26	high	38.0	(965)	2 473 700	60	2 473 760	b

a. Specimen failed by pulling out of end fitting.
b. Test terminated without failure.
c. One strand failed after approximately 1 400 000 cycles (Fig. 3). Test subsequently terminated without further failure.
d. Specimen failed in free length (Fig. 4a).

4.3 Residual Strength Tests

The residual strengths, of the seven specimens which had survived the fatigue tests, were measured with tensile tests. These tests were performed in a 400 000-lbf (1.78-MN) capacity, screw-powered testing machine [1] at a crosshead speed of 0.75 in/min (0.32 mm/s). Each specimen was subjected to ten cycles of load, from zero to a predetermined load and back to zero, before the load was increased to failure. For Specimen No. 8, which had previously suffered a fatigue failure of one of its end fittings (Figure 7), the potting head was clamped directly into the tapered wedge grips of the testing machine. The teeth marks seen on the potting head in the figure are the result of this gripping.

The results of the tests are given in Table 9. Of the seven specimens tested, two failed in their free lengths at loads substantially below their rated breaking loads. One of these, Specimen No. 17 (Table 8) had experienced a failure of one of its strands in its fatigue test, and the other, Specimen No. 8 (Table 6), probably sustained shock-loading damage in the recoil from the fatigue failure of its end fitting. The other five specimens all failed in or near an end fitting. The breaking loads for four of these specimens closely approached, or exceeded, the respective rated breaking loads. The fifth, Specimen No. 26, a high-capacity cabled-strand specimen, failed at only 78 percent of its rated breaking load. The failure occurred adjacent to both of its end fittings despite the fact that there had been no seepage of potting compound from the fittings. See Figure 4b.

5. SIMULATED WEATHERING STUDIES

The degrading effects of weather were simulated by means of environmental stress-rupture tests in which sling-leg specimens, under constant tensile loads, were exposed to accelerated weathering conditions. These conditions, adapted from Procedure C of ASTM Designation D1501 [2], consisted of the following sequence of environments in each 24-hour period:

2 h in an ambient temperature, saturated humidity environment;
2 h under heat and ultraviolet light;
2 h under saturated humidity as above;
18 h under heat and ultraviolet light.

This 24-hour cycle was repeated without interruption for a total duration of 240 hours unless the specimen failed sooner.

5.1 Test Equipment

The required tensile loads were applied to the specimens by 30 000-lbf (130-kN) capacity, horizontal, dead-weight, lever-arm, creep-testing machines (Figure 8) which can accomodate tensile specimens up to nine feet (2.7 m) long [3]. The test environments were provided by environmental chambers installed in the machines.

Table 9 - Tensile Tests of Fatigued Specimens

Rope configuration	Specimen No.	Rated breaking load		Free length before cycling		Cycling load		Free length after cycling		Measured breaking load		Remarks
		lbf	(kN)	in	(mm)	lbf	(kN)	in	(mm)	lbf	(kN)	
parallel	12	17 500	(78)	43.5	(1105)	8500	(37.8)	43.6	(1107)	17 900	(79.6)	a
parallel	15	36 000	(160)	40.0	(1016)	18 000	(80.1)	b	(b)	35 400	(157.5)	a
cabled	8	17 500	(78)	b	(b)	8400	(37.4)	b	(b)	14 100	(62.7)	c
cabled	13	17 500	(78)	26.4	(671)	8500	(37.8)	26.4	(671)	17 750	(79.0)	d
cabled	16	36 000	(160)	26.3	(668)	18 000	(80.1)	26.5	(673)	35 300	(157.0)	e
cabled	17	36 000	(160)	45.1	(1146)	18 000	(80.1)	45.7	(1161)	32 450	(144.3)	c
cabled	26	56 000	(249)	40.0	(1016)	28 000	(124.6)	40.4	(1026)	43 900	(195.3)	f

a. Specimen failed near end fitting where potting compound had seeped into free length.
b. Not measured.
c. Specimen had sustained previous damage (see Section 4.3) and failed in free length.
d. Specimen failed inside one end fitting.
e. Specimen failed by pulling out of one end fitting.
f. Specimen failed adjacent to both end fittings (see Figure 4b). Potting compound had not seeped out of the fittings.

The housing for each chamber was a 10-in (0.25-m) diameter asbestos-cement pipe, 4 ft (1.2 m) long. The chamber was mounted in the machine such that the specimen, with pull rods attached, passed concentrically through it with approximately one-half of the specimen, including one end fitting, located inside it. The other half of the specimen and its end fitting remained outside of the chamber. The ends of the chamber were fitted with transparent plastic windows having central holes to enable the pull rod on one end, and the specimen on the other, to pass through. Ultraviolet light was supplied by twelve 48-in (1.2-m) tubular fluorescent sunlamps which were uniformly spaced around, and affixed to, the inner surface of the asbestos-cement pipe.

The saturated humidity environment was provided by an atomizing nozzle mounted through a small hole in one of the plastic windows. The nozzle was powered by a pneumatic mist generator and delivered a soft, finely divided spray of distilled water to the interior of the chamber. The nozzle was oriented so that the spray did not impinge directly on the specimen. The rate of water consumption was adjusted by regulating the air flow rate to maintain a light film of condensate on the windows of the chamber.

The 24-hour exposure cycle was controlled with an automatic cycle timer.

In the first test conducted with this apparatus, it was observed that temperatures in the environmental chamber reached approximately 200 °F (93 °C) during the sunlamp exposures. In the subsequent tests a small blower was used to circulate air through the chamber during the sunlamp exposures in order to limit the maximum temperatures to more reasonable values.

5.2 Tests and Results

Seven tests were performed. The tensile load applied to each specimen during the environmental exposure was one-half of its rated working load (Table 1). The results of the tests are given in Table 10.

Four of the specimens survived the simulated weathering tests without failure. Three specimens, all of the parallel-strand variety, failed by pulling out of the end fitting which had been exposed to the weathering. Examination of the specimens following these tests showed that the potting compound which had been used in the end fittings on the parallel-strand rope specimens had softened excessively as a result of the environmental exposures. This effect was not noted for the potting compound used for the cabled-strand rope specimens.

The four specimens, which survived the simulated weathering tests, were then tested in tension following the same procedure used for the specimens which had survived the fatigue tests (Section 4.3). The results of these tension tests are given in Table 11.

Table 10 - Simulated Weathering Tests

Rope config.	Specimen No.	Tensile capacity	Free length		Tensile load		Temperature[a]		Test duration	Remarks
			in	(mm)	lbf	(kN)	°F	(°C)	h	
parallel	18	low	b	(b)	5000	(22.2)	200	(93)	<24	c
parallel	19	low	48.8	(1240)	5000	(22.2)	90	(32)	202	c
parallel	21	medium	35.6	(904)	12 500	(55.6)	100[d]	(38)	207[e]	c
parallel	22	high	33.2	(843)	20 000	(89.0)	102	(39)	240	f
cabled	20	low	25.4	(645)	5000	(22.2)	92	(33)	240	f
cabled	23	medium	26.0	(660)	12 500	(55.6)	92	(33)	240	f
cabled	24	high	38.2	(970)	20 000	(89.0)	98	(37)	240	f

a. Maximum temperature per cycle, ± 5 °F (± 3 °C); usually attained during 18-h interval under sunlamp exposure.
b. Not measured.
c. Failed by pulling out of end fitting in environmental chamber.
d. Except 125 °F (52 °C) during one 18-h interval due to blockage in air stream.
e. ± 7.5h; timer cut-off switch malfunctioned.
f. Test terminated without failure.

Table 11 - Tensile Tests of Artificially Weathered Specimens

Rope configuration	Specimen No.	Rated breaking load	Free length before cycling	Cycling load	Free length after cycling	Measured breaking load	Failure
		lbf (kN)	in (mm)	lbf (kN)	in (mm)	lbf (kN)	
parallel	22	56 000 (249)	34.1 (866)	28 000 (124.6)	34.2 (869)	>46 300 (>206.0)	a
cabled	20	17 500 (78)	26.0 (660)	8500 (37.8)	26.2 (665)	17 300 (77.0)	b
cabled	23	36 000 (160)	26.5 (673)	18 000 (80.1)	26.6 (676)	31 900 (141.9)	c
cabled	24	56 000 (249)	39.2 (996)	28 000 (124.6)	39.5 (1003)	51 200 (227.7)	b

a. Pull rod failed; strength of specimen indeterminate.
b. Specimen failed in free length.
c. Specimen failed adjacent to end fitting which had been outside of environmental chamber.

In the tension test of parallel-strand Specimen No. 22, one of the tensile pull rods failed at 46 300 lbf (206.0 kN), due to a machining defect which had not been detected previously. The recoil from this failure appeared to damage the specimen near the end fitting which had been exposed to the simulated weathering. In a subsequent re-test, the specimen failed at this damaged site, at a load of 43 500 lbf (193.5 kN).

One of the three cabled-strand specimens failed, surprisingly, adjacent to its end fitting which had been <u>outside</u> of the environmental chamber during the simulated weathering exposure. The other two cabled-strand specimens failed in their free lengths; one at a load close to its rated breaking load, and the other at a load 9 percent below its rated breaking load. Removal of the braided polyester jacket from the latter specimen revealed that the rope, in that portion of the specimen which had been exposed to simulated weathering, had become discolored. The fibers, usually yellow, had assumed a deeper, orange tint. This discoloration was not observed on any of the other specimens tested.

6. PERMANENT ELONGATION

The specimens tested in this investigation usually sustained some permanent (or quasi-permanent) elongation as a result of the tensile loads which were imposed upon them. The measurements of free length, given in Tables 4, 6, 8, 9, 10 and 11, permit the permanent elongations to be calculated. These calculations suggest the following conclusions, which must be considered only approximate and unsubstantiated, since the volume of data upon which they are based is very sparse.

The application of five or ten load cycles up to approximately one-half of the rated breaking load of a specimen produced permanent elongations of 0 to 1.5 percent. The magnitude of the elongation tended to increase with rope diameter and, surprisingly, was not heavily dependent on whether the cycles were applied to a previously untested specimen, to one which had been fatigued, or to one which had been exposed to simulated weathering under load for 240 hours.

The fatigue tests produced permanent elongations which also tended to increase with rope diameter. These elongations ranged up to 1.5 percent for parallel-strand ropes, and up to 5.3 percent for cabled-strand ropes.

The simulated weathering exposures produced permanent elongations (i.e., creep) of less than 3 percent. These elongations did not appear to be very dependent on rope configuration or rope diameter.

The largest total permanent elongation was observed on high-capacity cabled-strand Specimen No. 26, which sustained 5.3 percent elongation in its fatigue test and another 1.0 percent in the ten load cycles applied prior to its subsequent tensile test (Tables 8 and 9). The largest

permanent elongation observed on the parallel-strand specimens was 3.0 percent on Specimen No. 22. This high-capacity specimen experienced 2.7 percent elongation as a result of its simulated weathering test and another 0.3 percent in the ten load cycles applied prior to its subsequent tensile test (Tables 10 and 11).

7. DISCUSSION

7.1 Breaking Loads

The tests which were performed to evaluate the tensile breaking loads of the specimens in their as-received conditions (Table 4) all culminated in failures which were attributable to inadequacies of the end fittings. Because of this, the true strengths of the aramid-fiber ropes were not determinable and a comparison of the relative strengths of the parallel-strand and the cabled-strand ropes was not possible. In spite of the undesirable failure mode, some specimens of both configurations attained over 98 percent of their rated breaking loads before failure.

7.2 Fatigue Endurance

Out of twelve specimens subjected to fatigue loading, only one failed to endure the imposed fatigue spectrum because of damage incurred in the rope itself. All of the other specimens either survived the entire spectrum or failed due to an end-fitting inadequacy. The single rope failure occurred in a high-capacity cabled-strand specimen (No. 25, Table 8). However, another high-capacity cabled-strand specimen survived the same fatigue spectrum. So it is not known, on the basis of these limited data, whether or not the lone rope failure reflects a weakness in fatigue that is characteristic of this rope style. No high-capacity parallel-strand rope specimens were tested in fatigue, so a direct comparison of the two high-capacity configurations in fatigue is not possible.

In tensile tests of the seven specimens which survived their imposed fatigue spectrums, six failed due to end-fitting inadequacies and only one (Specimen No. 17, Tables 8 and 9) due to fatigue damage sustained by the rope itself. This medium-capacity cabled-strand specimen attained only 90 percent of its rated breaking load. Another medium-capacity cabled-strand specimen attained 98 percent of its rated breaking load before pulling out of one of its end fittings so here, too, it is not known whether or not the lower value reflects some inherent weakness that is characteristic of this rope style. A medium-capacity parallel-strand specimen also attained more than 98 percent of its rated breaking load following fatigue cycling. In fact, most of the specimens which had survived their imposed fatigue spectrums attained more than 98 percent of their rated breaking loads before failing due to end-fitting inadequacies. A notable exception was the high-capacity cabled-strand

specimen, referred to above, which had survived the fatigue spectrum. In its subsequent tensile test, this specimen (No. 26, Table 9) failed at an end fitting at only 78 percent of its rated breaking load.

Since no high-capacity parallel-strand specimens were studied in fatigue, there are no data to indicate whether or not the fatigue strength of the parallel-strand configuration might be better than that of the cabled-strand configuration in the high-capacity size.

7.3 Weatherability

Out of seven specimens subjected to simulated weathering conditions under load, three failed due to end-fitting inadequacies and four survived the entire 240-hour exposures. In subsequent tensile tests of these four specimens, only two, both having cabled-strand configurations, failed in a manner which reflected the true residual strengths of the ropes (Table 11). One of these, a low-capacity specimen (No. 20), attained 99 percent of its rated breaking load but the other, a high-capacity specimen (No. 24), only reached 91 percent of its rated breaking load before failing in its free length. The latter specimen was the only one subjected to simulated weathering which was not fabricated with a relatively impervious jacket, and the rope in this specimen was the only one which had visibly degraded due to the applied environment. Two other tests culminated in failures at even lower percentages of the rated breaking loads, but the modes of failure do not permit any conclusions to be drawn regarding the relative performances of the parallel-strand and the cabled-strand configurations.

7.4 End Fittings

All of the parallel-strand specimens were fitted with potted, open spelter sockets. The failures of all but one of these specimens was clearly attributable to inadequacies related to the fittings. Two such inadequacies were predominant. One was the potting technique, which permitted potting compound to seep into the rope fibers outside of the fitting before it was cured, thereby diminishing the flexibility of the rope near the fittings. The second inadequacy was the potting compound itself. While the potting compound exhibited the flexibility, under normal environmental conditions, that NBS work has shown to be desirable [4], its degradation under the simulated weathering exposures was excessive.

These two inadequacies were not as predominant in the end fittings used on the cabled-strand specimens. Seepage of the potting compound was a serious problem only on the low-capacity specimens. It appeared as though the manufacturer of the cabled-strand specimens had somehow solved the seepage problem before assembling the medium- and high-capacity specimens. The potting compound used on the cabled-strand specimens did not appear to suffer serious degradation under the simulated weathering conditions; but, because it was rather hard, it may have

contributed to a number of other undesirable failures. Two specimens failed adjacent to end fittings where seepage had not occurred, and one failed inside an end fitting. These failures occurred at loads corresponding to 78, 89 and 101 percent of the respective breaking loads of the specimens*, and appeared to have been induced by the stress concentrations imposed by the end fittings. NBS work has shown that these stress concentrations can be reduced by using a more flexible potting compound [4]. Of course, it is not immediately obvious that a suitable potting compound can be formulated which is flexible under ordinary environmental conditions yet does not degrade rapidly under severe environments.

End-fitting parameters other than those related to the potting compound also merit discussion. It seems unreasonable to expect that commercial end fittings, designed for use on steel wire rope or on low-modulus, synthetic fiber ropes, would necessarily perform well on aramid-fiber rope. Most of the end fittings used in this investigation fall into these categories. However, two of the end-fitting types used in this investigation (Figures 4b and 5) were apparently designed specifically for the sling-leg specimens. Some measure of success was thereby achieved, since in three tests involving these end fittings, two culminated in failures which occurred in the free lengths of the ropes.

Going a step further, it is not even true that end fittings of the potted compression variety are necessarily the best for high-strength ropes. Studies involving fiberglass rope, for example, have shown that dead-end guy grips and potted, shear-type end fittings** both performed better than potted compression-type end fittings [4]. Dead-end guy grips, unfortunately, exhibited low fatigue strengths when the cable specimens, to which they were attached, were cycled between a slack and a taut condition [5]. However, the fatigue failures occurred in the outside loops of the dead-end guy grips and suitable reinforcement could, perhaps, rectify this deficiency. The potted shear-type end fittings have not been evaluated under fatigue loading.

7.5 Synergistic Effects

In this investigation the effects of fatigue loading and of weathering were evaluated separately, using different specimens, although a helicopter sling in service experiences both effects simultaneously. It may be well to note, therefore, that tests of fiberglass ropes revealed significantly reduced fatigue strengths following exposures to simulated weathering conditions [6].

*Specimen Nos. 26 (Table 9), 24 (Table 11) and 13 (Table 9), respectively.

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8. CONCLUDING REMARKS

As part of a program to develop improved external cargo slings for helicopters, a test program was carried out on prototype sling-leg specimens fabricated from aramid-fiber ropes with potted, compression end fittings. The ropes included both parallel-strand and cabled-strand varieties, in three different tensile capacities. The test program was intended to provide data on the actual tensile breaking loads of the ropes and on their resistances to fatigue damage and to weathering. Most of the specimen failures incurred in the tests were directly attributable to inadequacies in the end fittings. This fact, together with the sparse amount of data acquired (only twenty-six specimens were tested), prevented complete evaluation of the maximum capabilties of the ropes themselves. Therefore, the following observations are offered in the absence of fully substantiated conclusions.

1. No evidence was obtained which indicates that new sling legs with adequate end fittings would be incapable of meeting the specified breaking load requirements.

2. Some variability was observed in the performance of the cabled-strand ropes, which suggests that their resistances to fatigue damage -- particularly in the medium- and high-capacity sizes -- may not be entirely adequate for the intended application. This observation should not be interpreted as necessarily favoring the parallel-strand configuration, since the data obtained on the latter were simply inadequate for a comparable judgement. The endurance of sling legs fabricated with either rope configuration, and particularly the parallel-strand variety, could be improved with more adequate end fittings.

3. No evidence was obtained which indicates that the sling legs could not demonstrate acceptable weather resistance if terminated with adequate end fittings and protected with relatively impervious jackets. Regarding the latter, the weathering protection provided by a braided jacket appeared unsatisfactory in comparison with that which was provided by extruded polyurethane and neoprene-impregnated, braided jackets.

This test program was undertaken because aramid-fiber ropes appear to offer advantages, in terms of strength/weight and flexibility properties, for airborne cargo sling applications. The results which were obtained do not contradict this premise and it is felt, therefore, that further development and testing of aramid-fiber slings is warranted. This effort should concentrate, primarily, on the development of improved end fittings tailored to the characteristics of aramid-fiber rope as well as the demands of the intended application.

9. REFERENCES

1. Chwirut, D. J. (coordinator), Research and Testing Facilities of Engineering Mechanics Section, National Bureau of Standards, Washington, D. C., NBS Spec Publ 370 (1973).

2. American Society for Testing and Materials, Standard Recommended Practice for Exposure of Plastics to Fluorescent Sunlamp, ASTM Designation D1501-71, 1975 Annual Book of ASTM Standards, Part 35 (1975).

3. Marlowe, D. E., Halsey, N., Mitchell, R. A. and Mordfin, L., Non-Metallic Antenna-Support Materials, First Annual Interim Report, NBSIR 73-233 (April 1973).

4. Halsey, N., Mitchell, R. A. and Mordfin, L., Evaluation of GRP Rod and Rope Materials and Associated End Fittings, NBSIR 73-129 (Dec. 1972).

5. Halsey, N. and Quindry, T. L., Relative Performance of Combinations of Guy Grips and Attachments, NBS Report 10849 (May 1972).

6. Halsey, N., Properties of Glass Fiber-Reinforced Polymers for Application to Guy-Insulator Systems of Communication Towers, Phase 2, Test Methods and Evaluations of Glass Fiber-Reinforced Polymer Rods for Use in Guy-Insulator Systems of Loran C Towers, NBS Report 10261 (June 1970).

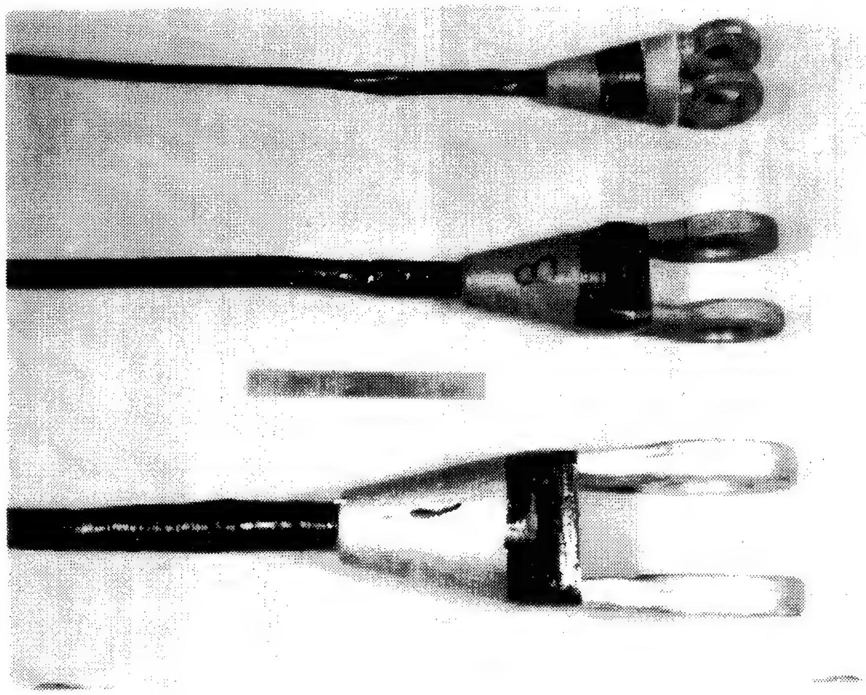

Figure 1. Sling-leg specimens in three tensile capacities, fabricated from parallel-strand ropes with neoprene-impregnated, braided nylon jackets and potted, open spelter sockets. (Disregard the numerals on the sockets; they are not specimen designations.)

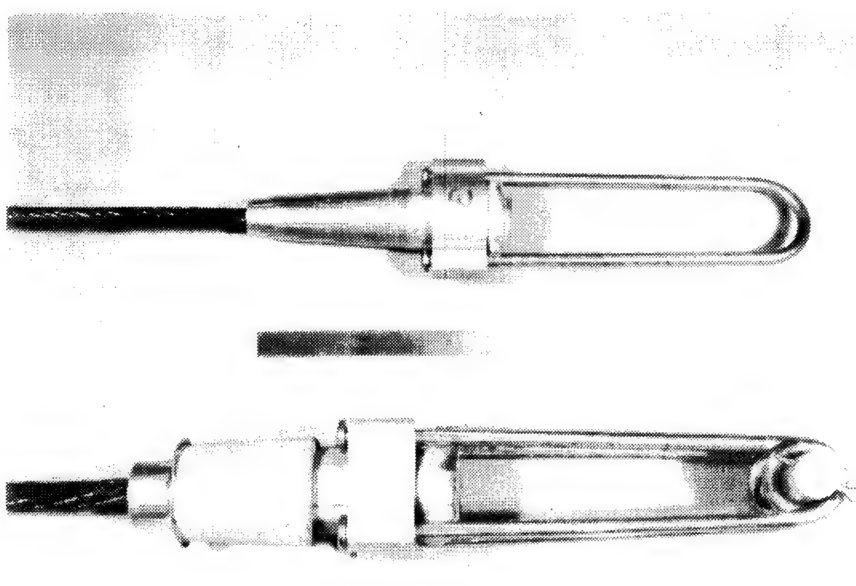

Figure 2. Sling-leg specimens in two tensile capacities, fabricated from cabled-strand ropes with extruded polyethylene jackets.
(a), above: low-capacity specimen (No. 3) with potting head.
(b), below: medium-capacity specimen (No. 23) with reinforced potting head.

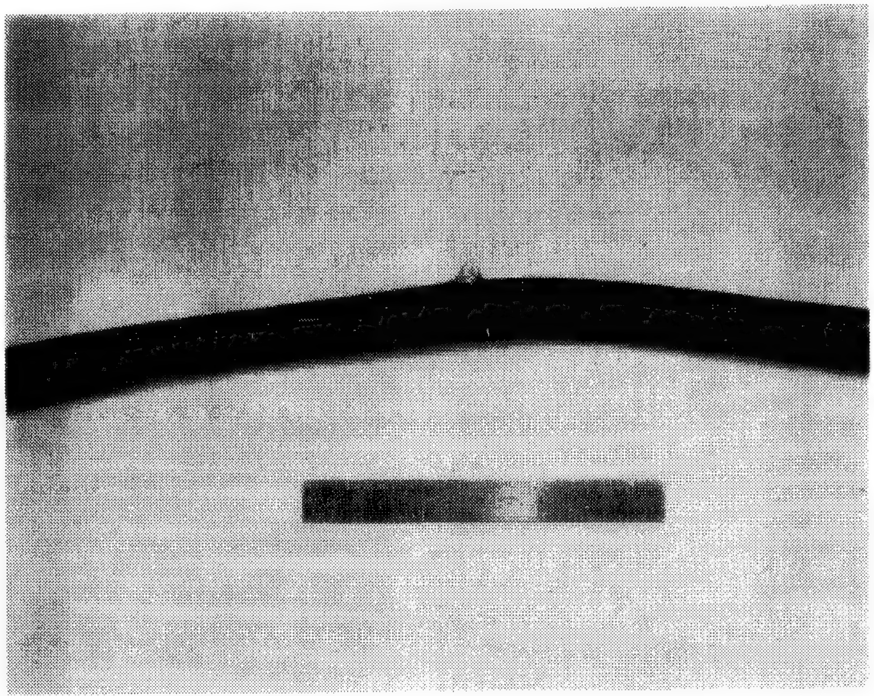

Figure 3. Sling-leg specimen (No. 17) with a rope strand that failed in fatigue and punctured the polypropylene jacket. This is a medium-capacity specimen, fabricated from cabled-strand rope.

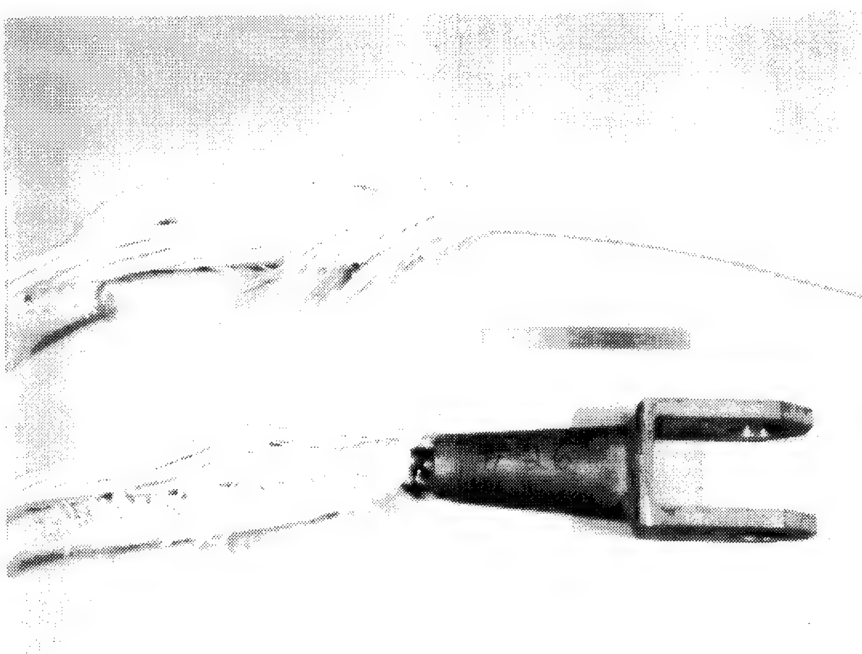

Figure 4. High-capacity sling-leg specimens after test. These specimens were fabricated from cabled-strand ropes with braided polyester jackets.

(a), above: Specimen No. 25 with free-length failure incurred in fatigue.

(b), below: Specimen No. 26 with failure adjacent to experimental end fitting, incurred in tension test following fatigue loading.

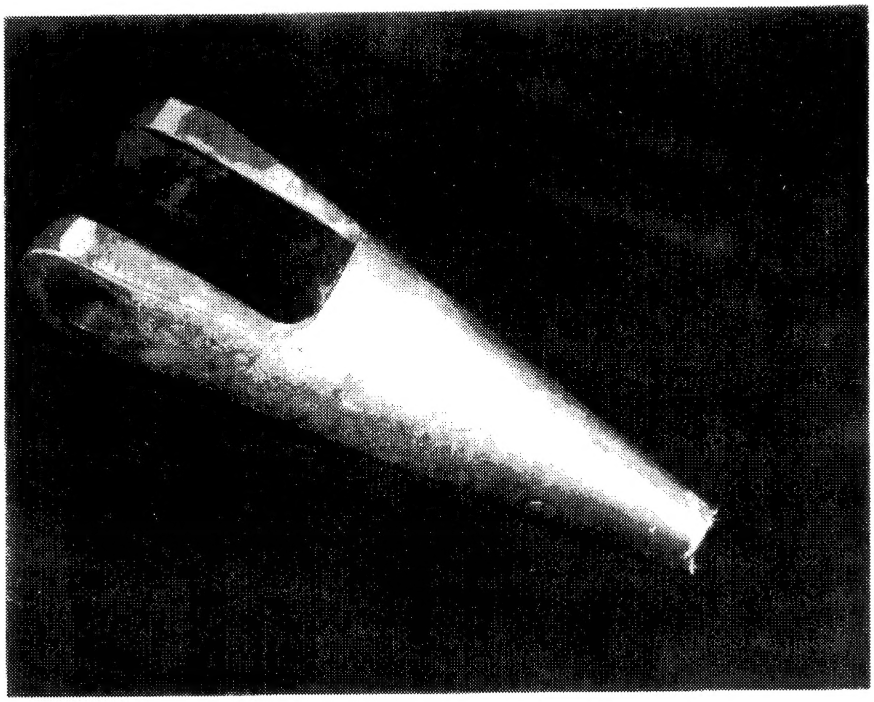

Figure 5. Proprietary, experimental, phosphor-bronze end fitting. Fittings of this kind were used on one high-capacity, cabled-strand, sling-leg specimen (No. 25).

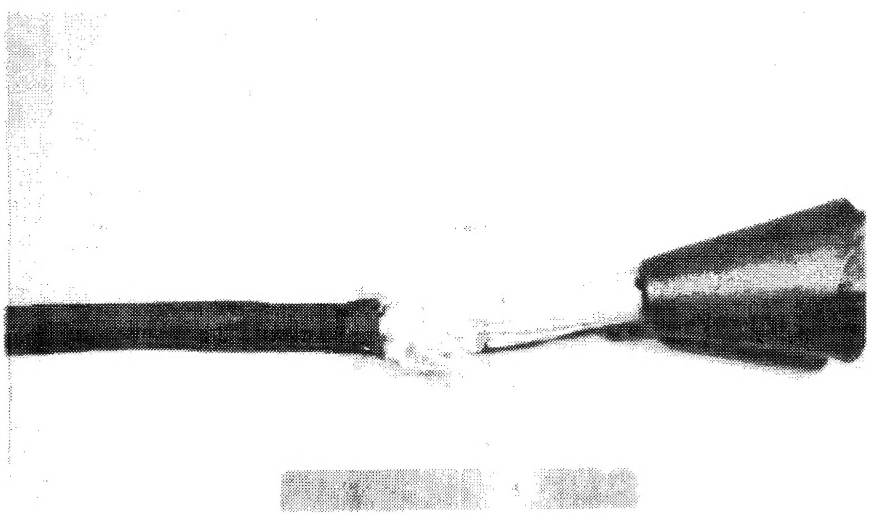

Figure 6. Parallel-strand sling-leg specimen with failure adjacent to an end fitting where the potting compound had seeped into the rope fibers and diminished their flexibility.

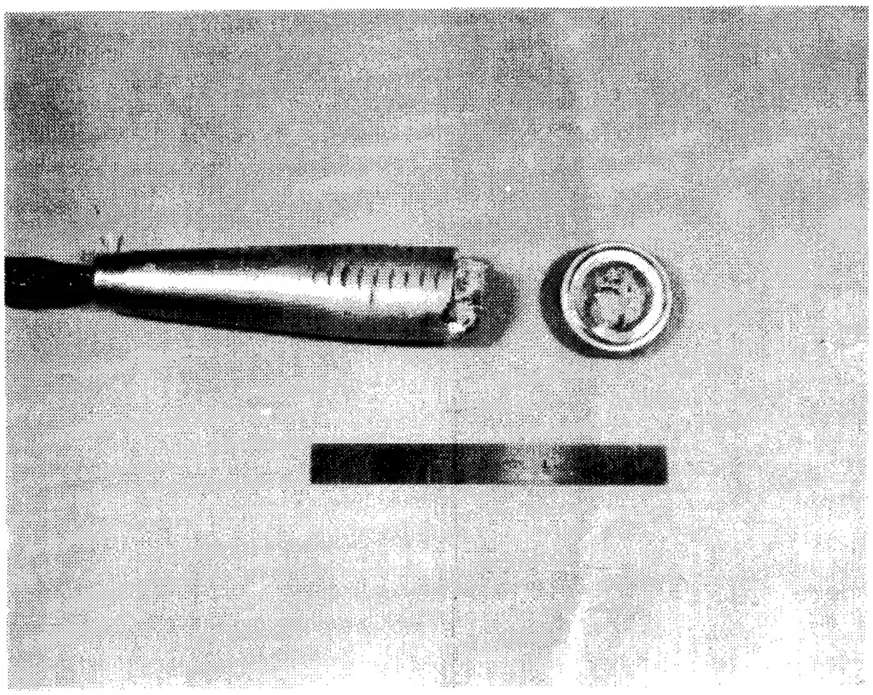

Figure 7. Fatigue failure of potting head on Specimen No. 8. This is a low-capacity, cabled-strand, sling-leg specimen which was subsequently tested in tension by gripping the remaining portion of the potting head with wedge grips.

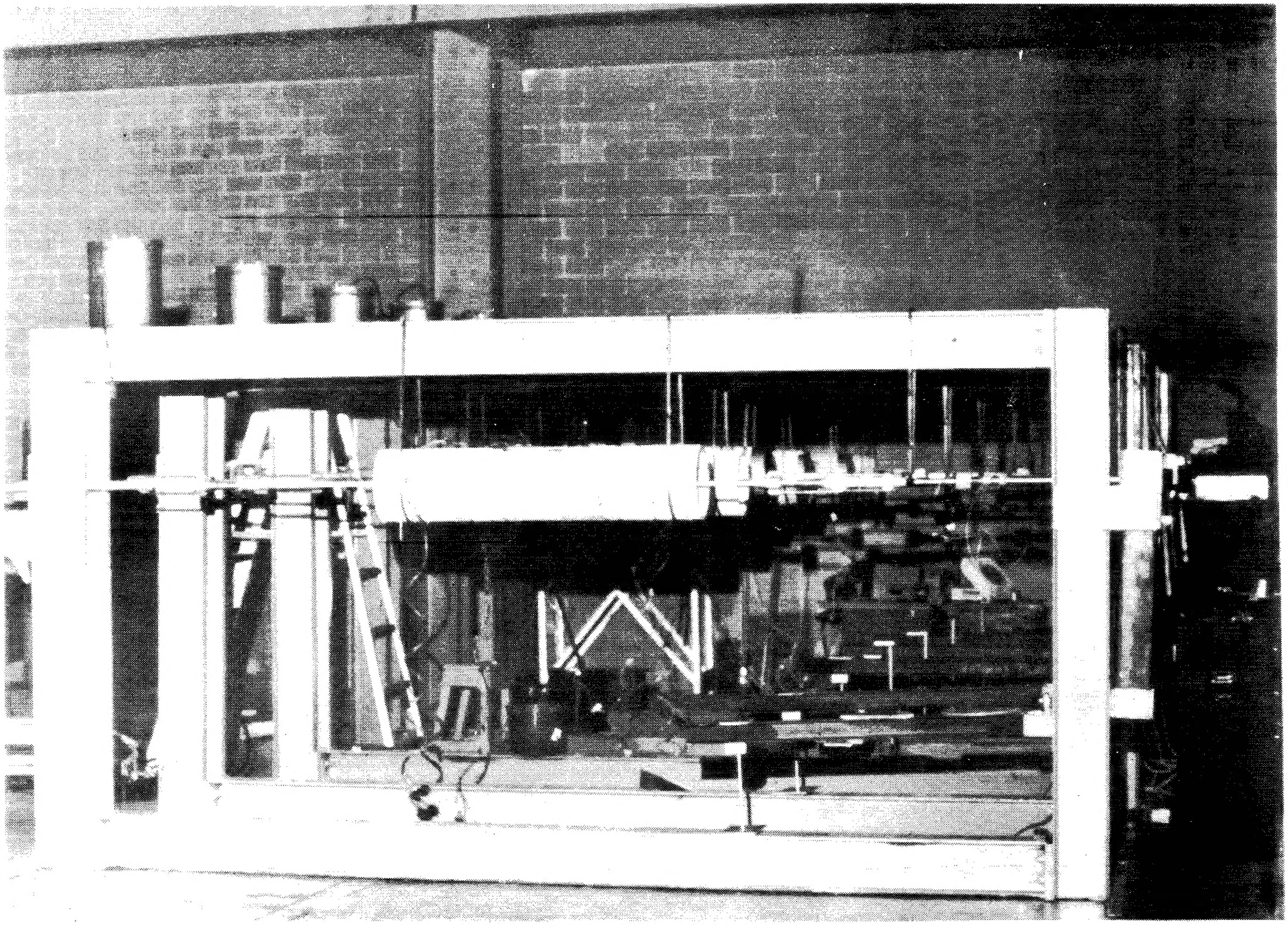

Figure 8. NBS high-capacity creep-testing machines, shown here with environmental chambers installed for simulated weathering tests of pultruded fiberglass rod specimens under tensile load.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Tests were carried out on twenty-six sling-leg specimens, fabricated from aramid-fiber ropes, as part of a program to develop improved external cargo slings for helicopers. The ropes included both parallel-strand and cabled-strand varieties, in three different tensile capacities. The tests were intended to evaluate the reductions in rope strength caused by fatigue loading and by exposure to simulated weathering. It was found that the fatigue capabilities of some of the ropes may not be entirely satisfactory; but, because of inadequacies in the end fittings installed by the rope manufacturers, thorough evaluations were not possible. The results indicate that the performances of the ropes could be enhanced through the use of more efficient end fittings, and suggestions for the development of such end fittings are offered.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Aramid-fiber rope; breaking load, rope; cable, aramid-fiber; end fittings, rope; fatigue damage; rope, aramid-fiber; slings, cargo; terminations, rope; weathering, simulated.

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